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DOSIMETRIC MEASUREMENTS ON THE SECOND SOVIET SPACESHIP SATELLITE

(Dozimetricheskiye izmereniya na vtorom sovetskom kosmicheskom korable-sputnike)

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1. INTRODUCTION

In order to ensure the safety of astronauts, a detailed knowledge of the physical properties of the cosmic space is indispensable. Study of cosmic radiation is of particular importance. It includes the following forms of radiation:

1. Charged particle flux (protons with energies $E_p > 10^8$ eV in particular), penetrating into the solar system from the Galaxy depth, which is isotropic in space and practically uniform in time. This form of radiation - which in its narrow sense constitutes cosmic rays, has been known for a long time and comparatively well studied. The cosmic ray intensity in the interplanetary space constitutes during the years of solar activity maximum 2 — 2.5 particles $\cdot cm^{-2} \cdot sec^{-1}$ [1]. As the solar activity decreases, the intensity of cosmic rays increases twofold. [2].

2. Charged particles (protons with energies of about 10^8 eV) and γ - quanta, whose appearance is linked with chromospheric flares on the Sun. Most of these flares are observed during the maximum period of the 11-year cycle of solar activity. During the last years several flares were observed

after which a 10^3 times and higher increase in the proton flux took place in the near-the Earth space. [3].

3. Radiation originating from the Earth's radiation belts. At present the existence of two such fundamental radiation belts is established [4]. The outer belt is distant from the Earth by 13 to 50 thousand kilometers from the Earth in the equatorial plane. It basically consists of electrons with mean energy of the order of 10^5eV. According to measurements on cosmic rockets, the maxium radiation intensity in the outer belt corresponds to the power of a dose to 10 p. $hour^{-1}$ (under a substance layer with about 1 $g.cm^2$ thickness) [5]. The processes linked with chromospheric flares in the Sun have a substantial influence on the intensity and on the position of the outer radiation belt [5]. The inner radiation belt is situated at distances from 600 to 4500 km from the surface of the Earth (in the magnetic equator plane), and it contains, besides electrons, protons with energies of the order of 10^8 eV. The radiation intensity in this belt is also high: it reaches 10 p· hour for the dose power under 1 $g \cdot cm^2$ substance layer [5, 6].

The existence of the above-described types of radiation, which may present under specific conditions a serious danger for biological objects, requires the carrying out of dosimetric control aboard spacecrafts. This requirement becomes particularly obvious, if account is taken of possible fast variations in intensity of either form of cosmic radiation caused by solar processes.

The second Soviet spaceship-satellite was launched on 19 August 1960 Its orbit plane was inclined at an angle of 65° to the equator plane.

its average altitude above ground was about 320 kilometers.

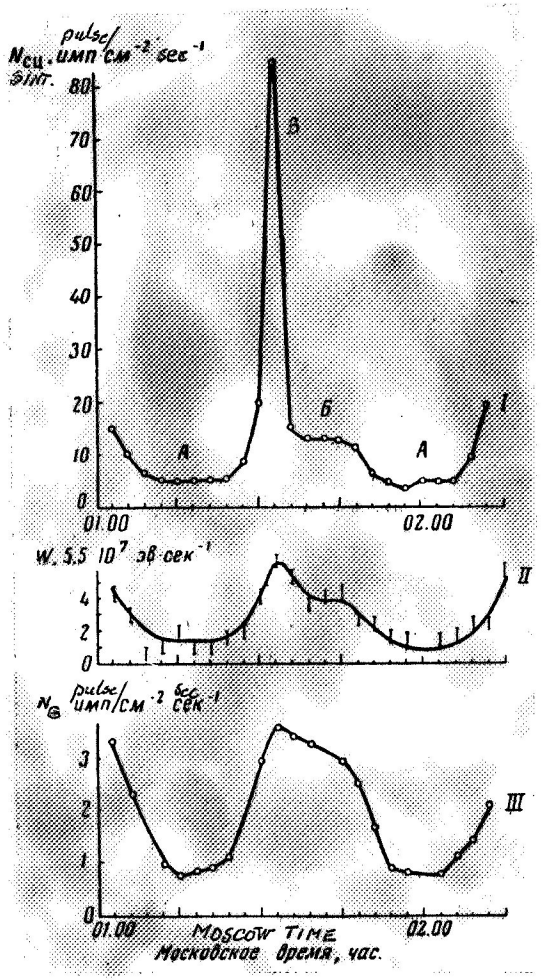

Fig. 1. I - intensity registered by the inside scintillation counter with a 25 keV thresh. II — energy liberation in the NaJ crystal per time unit. III — intensity registered by the STS-5 gas-discharge counter.

Two scintillation and two gas-discharge counters were installed aboard the spaceship. [7]. One of the scintillation counters was installed outside the instrument compartment, and was designed for the registration of soft electrons (with energies $E_e \geqslant 30$ keV), while the remaining counters were placed inside the spacecraft near the capsule with test animals. All information obtained during 19-20 August 1960 by the radiometric apparatus, was entered into the memory device, and then telemetered to the Earth.

2. EXPERIMENTAL RESULTS.

Readings of counters placed inside the spaceship for one of the portions of its trajectory are plotted in Figure 1. They refer to the gas-discharge counter STS-5 and the scintillator counter (NaJ crystal) which registered γ - quanta and charged particles (with a 25 keV counting threshold), and also the aggregate energy liberation of ionizing radiations in the crystal.

The change in counter readings (about fourfold) during spaceship's transition from the equatorial region (portion A), to higher latitudes (Б)

is explained by latitude effect of cosmic rays. At the same time, the intensity registered by the counter STS-5 increased from 0.8 to 3.2 $p \cdot cm^{-2} \cdot sec^{-1}$, the energy liberation on the crystal — from $5.5 \cdot 10^7$ to 2.2 10^8 eV sec^{-1}, and the intensity registered by the scintillator — from 3.5 to 13 $pulse \cdot cm^{-2} \cdot sec^{-1}$. The sharp increase in the scintillator's counting rate over the portion B (at 01 30 — 01 40 hours), attended by a certain increase in the energy liberation in the crystal and an insignificant increase of counter's STS-5 counting rate may be explained by spaceship's passing through the lower region of the outer radiation belt (its protuberance, or "tongue" as the author puts it). At electron deceleration in the craft's casing, there appears an X-ray radiation, which is registered quite effectively by the scintillation counter (near 100 percent). The X-ray effective registration by the counter STS-5 is low (less than one percent). That is why the increase in counting rate in it is small.

The analysis of outer scintillator counter's readings led to the conclusion that radiation in the belts is anistropic, and that the energy flux under a $2 \cdot 10^{-3}$ $g \cdot cm^{-2}$ substance layer is about 10^{10} $eV \cdot cm^{-2} \cdot sec^{-1}$.

3. ABSORBED DOSE

The abosrbed dose inside the ship may be determined without a detailed examination of the composition and emission spectrum, by dividing the energy liberation in the crystal of sodium iodide by the crystal's weight (36.4 g). At the same time the errors will be so much the lower than the radiation is harder, i.e. than the boundary effect influence in the crystal is lesser. The so-determined power of the abosrbed dose during the flight of the second spaceship-satellite constituted as an average 7 mrad/day.

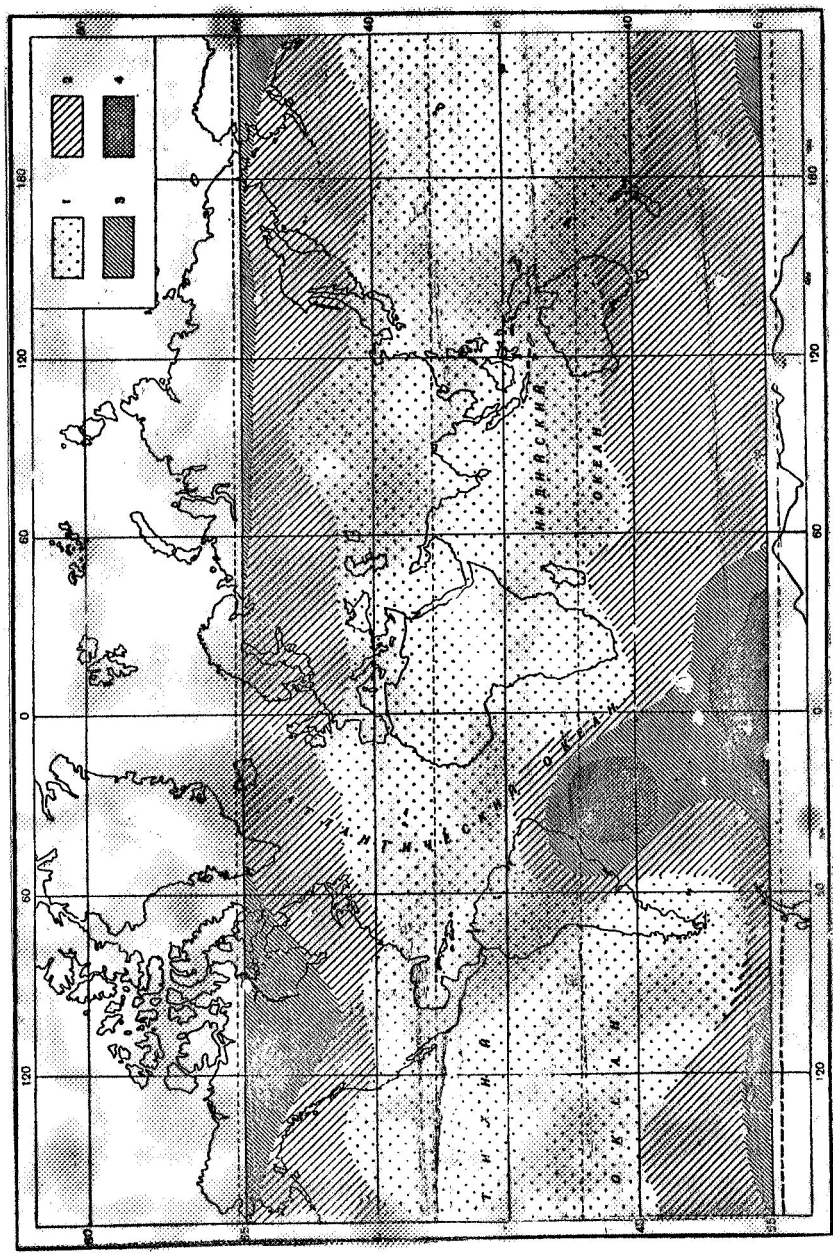

Fig. 2. Distribution of the power of absorbed dose at altitudes of the order of 320 km over the Earth's surface according to measurements aboard the second Soviet spaceship-satellite:

1 — from 3 to 10 mrad per day; 2 — from 10 to 20 mrad per day;
3 — " 20 to 30 " " 4 — " 30 to 50 " " "

At the same time, the dose obtained for a single convolution around the Earth varied from 0.35 to 0.70 mrad per day, which is explained by latitude and longitude effects of cosmic rays, and by the specific pattern of radiation distribution at the given altitude (Fig. 2).

4. COMPOSITION OF COSMIC RADIATION

The flux of primary charged particles in the region of the equator must constitute about 0.05 particles cm^{-2} sec^{-1} [8]. As it was already noted in part 2, the gas-discharge counter registered in the equatorial region 0.8 particles $\cdot$ $cm^{-2}.sec^{-1}$. At the same time, the rate of the scintillation counter reached 3.5 pulse $.cm^{-2}.sec^{-1}$. Hence we may conclude that the radiation registered in the equatorial region during the current experiment was basically of secondary origin , and that photon radiation predominates in its composition. Its source might have been the terrestrial atmosphere or the spaceship's body.

Let N_e be the flux of charged particles, and N_γ that of γ - quanta inside the spaceship-satellite. The counting rate of the scintillation counter will then be (upon reduction to 1 cm^2):

$$n = \varepsilon_e \cdot N_e + \varepsilon_\gamma \cdot N_\gamma, \qquad (1)$$

where ε_e and ε_γ are the effectiveness of charged particle and γ-quanta registration. The energy liberation W in the crystal (on cm^2 per sec) is

$$W = \varepsilon_e w_e N_e + \varepsilon_\gamma w_\gamma N_\gamma, \qquad (2)$$

where w_e and w_γ respectively are the mean energy liberation on one charged particle and on one γ-quantum.

Hence, considering $\varepsilon_e = 1$. we shall obtain

$$w_e = \frac{W}{N_e} - \left(\frac{n}{N_e} - 1\right) w_\gamma. \qquad (3)$$

The flux of charged particles N_e may be determined by the counting rate of the gas discharge counter m :

$$m = N_e + \eta_\gamma \cdot N_\gamma, \qquad (4)$$

where η_γ is the counter's STS-5 effectiveness in respect to the γ - radiation (effectiveness in regard to charged particles being 100%). Inasmuch as in our case $N_\gamma \cdot \eta_\gamma \ll N_e$, we may consider $m \approx N_e$.

Assuming now that all the energy liberation in the NaJ crystal is dependent upon the charged component, we have $w_e = \frac{W}{N_e}$ which in our case (see part 2) leads to

$$w_e = \frac{8 \cdot 10 \text{ eV cm}^{-2}\text{sec}^{-1}}{0.8 \text{ cm}^{-2} \text{ sec}^{-1}} = 10^7 \text{ev}.$$

This is the upper limit for the mean energy liberation on a single charged particle. For the relativistic proton the mean energy loss in the crystal of sodium iodide is $0.8 \cdot 10^7$ eV.

If we assume that counter-registered charged particles are relativistic, we may find the upper limit for the energy liberated on one quantum w_γ. From (1) and (3), we have

$$w_\gamma = \frac{W - N_e w_e}{n - N_e} \approx 6 \cdot 10^5 \text{ ev}$$

Thus, the radiation registered in the region of the geomagnetic equator consists of charged particles with an ionization near minimum, and of γ - quanta with energy not higher than $6 \cdot 10^5$ eV. Inasmuch as readings of all counters vary with latitude increase to about the same degree (see part 2), this conclusion may be extended

also to those polar regions, in which the effect of radiation belts are not felt.

5. RADIATION BELTS

Analysis of the readings of second spaceship-satellite's various pickups allowed to determine the disposition of radiation belts at the altitude of about 320 km above the Earth's surface.

The path of the second spaceship-satellite crossed sectors of the outer radiation belt in the regions of Siberia, North America, at the extreme south of the Pacific Ocean, and at the south of Indian Ocean.

The boundary of the outer radiation belt coincides rather well with the 70° magnetic inclination line on the low-latitude side of the Northern Hemisphere, and with the 66° line in the Southern Hemisphere. The outer radiation belt is bounded on the high-latitude side by the line of polar aurora maximum recurrence.

The counting rate of the scintillation counter sharply increased at entering the area of the outer radiation. The scintillation counter's peak indicated in Fig.1 corresponds to an 85 pulse $\cdot cm^{-2} \cdot sec^{-1}$ intensity. The maximum intensity registered by this counter at spaceship's crossing the radiation belt reached 570 pulse $\cdot cm^{-2} \cdot sec^{-1}$.

Knowing the counting rate accretion Δn, and that of energy liberation in the crystal per time unit ΔW at entering the radiation belt, one may determine the mean energy liberation in the crystal for one quantum $w_\gamma = \frac{\Delta W}{\Delta n}$. This gives for the case brought forth in part 2: $w_\gamma = 2.5 \cdot 10^5 eV$ The mean value of w_γ for the second spaceship's flight time constituted $2.0 \cdot 10^5$ eV.

The fact that the brehmstrahlung spectrum resulted harder in the outer radiation belt by comparison with that obtained in other works [4, 5] may be explained by a greater thickness of the substance layer surrounding the counters in the second spaceship-satellite [7].

Being aware of the energy W_1 under the substance layer, which is $2 \cdot 10^{-3}$ g $\cdot$ cm^{-2} (see part 2), the electron intensity in the outer radiation belt may be estimated. Estimating the mean energy of electrons as being $E_{cp} \approx 2 \cdot 10^5$ eV, we shall obtain

$$N = \frac{W_1}{E_{cp}} = \frac{10^{10} \text{ eV} \cdot \text{cm}^{-2} \cdot \text{sec}^{-1}}{2 \cdot 10^5 \text{ eV}} \approx 5 \cdot 10^4 \text{ par cm}^{-2} \text{sec}^{-1}.$$

Near the Brazilian coastline, the second spaceship hit the region of higher radiation intensity, in which protons were present. The presence of protons in the composition of the radiation provided the basis for acsribing this region to that of the inner radiation belt*). The power of the dose registered above this region exceeded 50 mRad per day. which is 7 times higher than the average of the dose's power (see Fig. 2).

6. COMPONENTS OF THE AGGREGATE DOSE

To estimate the biological effectiveness of the absorbed dose brought forth in part 3, we must know the relative contribution to that dose by the various forms of radiation.

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*) [A paper by S.N. Vernov & al. has been published since then by the USSR Ac.Sc. Doklady, V.140, No.5, pp. 1041-1044, 1961. This paper has been translated at NASA and bears the reference number TT-F-8127, of January 2nd, 1962.]

As was shown above, the following forms took part in the creation of the aggregate absorbed dose: 1) charged particles of cosmic origin (primary as well as secondary); 2) accompanying γ-radiation particles; 3) γ- brehmstrahlung created by electrons from the radiation belts; 4) protons of the inner radiation belt. The relative contribution of these various forms of radiation to the aggregate energy liberation, and consequently to the absorbed dose, is characterized by the following magnitudes: charged particles of cosmic origin — 80%; all forms of γ-radiation — 15%; protons from the inner radiation belt — 5%.

The relative biological effectiveness (RBE) for the γ-radiation in the interval observed by us, does not exceed 1. For the protons of the inner belt (their energy is of the order of hundreds of MeV), RBE is not higher than 10. As to charged particles of cosmic origin, it is difficult to draw at present any conclusion in regard to their RBE. At any rate, it is well known [9] that RBE is taken as 7 for the primary cosmic particles. Inasmuch as mesons, electrons and positrons may be present in the compostion of the secondary cosmic radiation, the RBE will be less than 7 for that component. But if despite that one takes 7 for the RBE of cosmic charged particles, the biological equivalent of the absobed dose's power registered on the second spaceship-satellite will amount to $\sim$40 mREm/day, and allowing for the NaJ crystal's texture non-equivalence — to 50 mRem/day. This only three times more than the maximum permissible daily dose of outer radiation at lengthy operation under the effect of ionizing radiations [10].

7. CONCLUSION

The power of the abosrbed dose, measured on the second Soviet spaceship-satellite constituted 7 mRad /day. Under certain assumptions relativley to the RBE of cosmic radiation's charged particles, this would correspond to 50 mRem /day. Such dose may be considered relatively safe for long flights along trajectories similar to those of the second Soviet spaceship-satellite during the quiet Sun period (it is assumed that the astronaut will then be protected by the same substance layer as that surrounding the radiometric apparatus aboard the second spaceship-satellite). Chromospheric flares may substantially increase the power of the dose.

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**** E N D ****

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Contractor for NASA HEADQUARTERS
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